CHAPTER 6

CONCRETE

Concrete is one of the most important construction materials. It is comparatively economical, easy to make, offers continuity and solidity, and will bond with other materials. The keys to good-quality concrete are the raw materials required to make concrete and the mix design as specified in the project specifications. In this chapter, we'll discuss the characteristics of concrete, the ingredients of concrete, concrete mix designs, and mixing concrete. We'll conclude the chapter with a discussion of precast and tilt-up concrete. At the end of the discussion, we provide helpful references. You are encouraged to study these references, as required, for additional information on the topics discussed.

CONCRETE CHARACTERISTICS

LEARNING OBJECTIVE: Upon completing this section, you should be able to define the characteristics of concrete.

Concrete is a synthetic construction material made by mixing cement, fine aggregate (usually sand), coarse aggregate (usually gravel or crushed stone), and water in the proper proportions. The product is not concrete unless all four of these ingredients are present.

CONSTITUENTS OF CONCRETE

The fine and coarse aggregates in a concrete mix are the inert, or inactive, ingredients. Cement and water are the active ingredients. The inert ingredients and the cement are first thoroughly mixed together. As soon as the water is added, a chemical reaction begins between the water and the cement. The reaction, called hydration, causes the concrete to harden. This is an important point. The hardening process occurs through hydration of the cement by the water, not by drying out of the mix. Instead of being dried out, concrete must be kept as moist as possible during the initial hydration process. Drying out causes a drop in water content below that required for satisfactory hydration of the cement. The fact that the hardening process does not result from drying out is clearly shown by the fact that concrete hardens just as well underwater as it does in air.

CONCRETE AS BUILDING MATERIAL

Concrete may be cast into bricks, blocks, and other relatively small building units, which are used in concrete construction. Concrete has a great variety of applications because it meets structural demands and lends itself to architectural treatment. All important building elements, foundations, columns, walls, slabs, and roofs are made from concrete. Other concrete applications are in roads, runways, bridges, and dams.

STRENGTH OF CONCRETE

The compressive strength of concrete (meaning its ability to resist compression) is very high, but its tensile strength (ability to resist stretching, bending, or twisting) is relatively low. Consequently, concrete which must resist a good deal of stretching, bending, or twisting—such as concrete in beams, girders, walls, columns, and the like—must be reinforced with steel. Concrete that must resist only compression may not require reinforcement. As you will learn later, the most important factor controlling the strength of concrete is the water-cement ratio, or the proportion of water to cement in the mix.

DURABILITY OF CONCRETE

The durability of concrete refers to the extent to which the material is capable of resisting deterioration caused by exposure to service conditions. Concrete is also strong and fireproof. Ordinary structural concrete that is to be exposed to the elements must be watertight and weather-resistant. Concrete that is subject to wear, such as floor slabs and pavements, must be capable of resisting abrasion.

The major factor that controls the durability of concrete is its strength. The stronger the concrete, the more durable it is. As we just mentioned, the chief factor controlling the strength of concrete is the water-cement ratio. However, the character, size, and grading (distribution of particle sizes between the largest permissible coarse and the smallest permissible fine) of the aggregate also have important effects on both strength and durability. However, maximum strength and durability will still not be attained unless the sand and coarse aggregate you use consist of well-graded, clean, hard, and durable particles free of undesirable substances (figure 6-1).

WATERTIGHTNESS OF CONCRETE

The ideal concrete mix is one with just enough water required for complete hydration of the cement. However, this results in a mix too stiff to pour in forms. A mix fluid enough to be poured in forms always contains a certain amount of water over and above that which will combine with the cement. This water eventually evaporates, leaving voids, or pores, in the concrete. Penetration of the concrete by water is still impossible if these voids are not interconnected. They may be interconnected, however, as a result of slight sinking of solid particles in the mix during the hardening period. As these particles sink, they leave water-tilled channels that become voids when the water evaporates. The larger and more numerous these voids are, the more the watertightness of the concrete is impaired. The size and number of the voids vary directly with the amount of water used in excess of the amount required to hydrate the cement. To keep the concrete as watertight as possible, you must not use more water than the minimum amount required to attain the necessary degree of workability.

GENERAL REQUIREMENTS FOR GOOD CONCRETE

The first requirement for good concrete is to use a cement type suitable for the work at hand and have a satisfactory supply of sand, coarse aggregate, and water. Everything else being equal, the mix with the best graded, strongest, best shaped, and cleanest aggregate makes the strongest and most durable concrete.

Second, the amount of cement, sand, coarse aggregate, and water required for each batch must be carefully weighed or measured according to project specifications.

Third, even the best designed, best graded, and highest quality mix does not make good concrete if it is not workable enough to fill the form spaces thoroughly. On the other hand, too much fluidity also results in defects. Also, improper handling during the overall concrete making process, from the initial aggregate handling to the final placement of the mix, causes segregation of aggregate particles by sizes, resulting in nonuniform, poor-quality concrete.

Finally, the best designed, best graded, highest quality, and best placed mix does not produce good concrete if it is not proper] y cured, that is, properly protected against loss of moisture during the earlier stages of setting.

CONCRETE INGREDIENTS

LEARNING OBJECTIVE: Upon completing this section, you should be able to identify the ingredients essential for good concrete.

The essential ingredients of concrete are cement, aggregate, and water. A mixture of only cement and water is called cement paste. In large quantities, however, cement paste is prohibitively expensive for most construction purposes.

PORTLAND CEMENT

Most cement used today is portland cement. This is a carefully proportioned and specially processed combination of lime, silica, iron oxide, and alumina. It is usually manufactured from limestone mixed with shale, clay, or marl. Properly proportioned raw materials are pulverized and fed into kilns where they are heated to a temperature of 2,700°F and maintained at that temperature for a specific time. The heat produces chemical changes in the mixture and transforms it into clinker—a hard mass of fused clay and limestone. The clinker is then ground to a fineness that will pass through a sieve containing 40,000 openings per square inch.

Types of Cement

There are five types of Portland cement covered under "Standard Specifications for Portland Cement." These specifications are governed by the American Society for Testing and Material (ASTM) types. Separate specifications, such as those required for air-entraining portland cements, are found under a separate ASTM. The type of construction, chemical composition of the soil, economy, and requirements for use of the finished concrete are factors that influence the selection of the kind of cement to be used.

TYPE I.— Type I cement is a general-purpose cement for concrete that does not require any of the special properties of the other types. In general, type I cement is intended for concrete that is not subjected

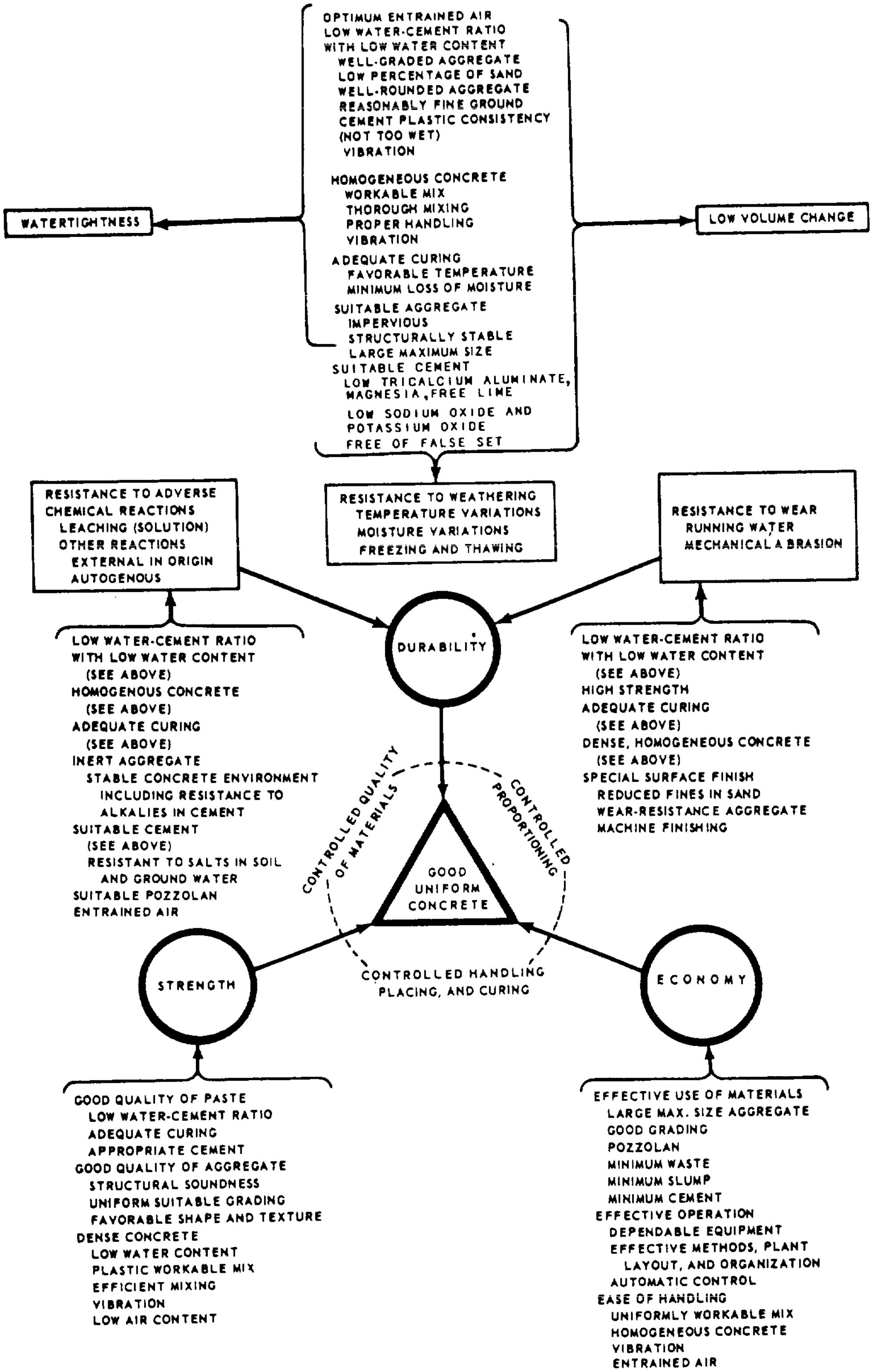

Figure 6-1.—The principal properties of good concrete.

to sulfate attack or damage by the heat of hydration. Type I portland cement is used in pavement and sidewalk construction, reinforced concrete buildings and bridges, railways, tanks, reservoirs, sewers, culverts, water pipes, masonry units, and soil-cement mixtures. Generally, it is more available than the other types. Type I cement reaches its design strength in about 28 days.

TYPE II.— Type II cement is modified to resist moderate sulfate attack. It also usually generates less heat of hydration and at a slower rate than type I. A typical application is for drainage structures where the sulfate concentrations in either the soil or groundwater are higher than normal but not severe. type II cement is also used in large structures where its moderate heat of hydration produces only a slight temperature rise in the concrete. However, the temperature rise in type II cement can be a problem when concrete is placed during warm weather. Type II cement reaches its design strength in about 45 days.

TYPE III.— Type III cement is a high-early-strength cement that produces design strengths at an early age, usually 7 days or less. It has a higher heat of hydration and is more finely ground than type I. Type III permits fast form removal and, in cold weather construction, reduces the period of protection against low temperatures. Richer mixtures of type I can obtain high early strength, but type III produces it more satisfactorily and economically. However, use it cautiously in concrete structures having a minimum dimension of 2 1/2 feet or more. The high heat of hydration can cause shrinkage and cracking.

TYPE IV.— Type IV cement is a special cement. It has a low heat of hydration and is intended for applications requiring a minimal rate and amount of heat of hydration. Its strength also develops at a slower rate than the other types. Type IV is used primarily in very large concrete structures, such as gravity dams, where the temperature rise from the heat of hydration might damage the structure. Type IV cement reaches its design strength in about 90 days.

TYPE V.— Type V cement is sulfate-resistant and should be used where concrete is subjected to severe sulfate action, such as when the soil or groundwater contacting the concrete has a high sulfate content. Type V cement reaches its design strength in 60 about days.

Air-Entrained Cement

Air-entrained portland cement is a special cement that can be used with good results for a variety of conditions. It has been developed to produce concrete that is resistant to freeze-thaw action, and to scaling caused by chemicals applied for severe frost and ice removal. In this cement, very small quantities of air-entraining materials are added as the clinker is being ground during manufacturing. Concrete made with this cement contains tiny, well-distributed and completely separated air bubbles. The bubbles are so small that there may be millions of them in a cubic foot of concrete. The air bubbles provide space for freezing water to expand without damaging the concrete. Air-entrained concrete has been used in pavements in the northern states for about 25 years with excellent results. Air-entrained concrete also reduces both the amount of water loss and the capillary/water-channel structure.

An air-entrained admixture may also be added to types I, II, and III portland cement. The manufacturer specifies the percentage of air entrainment that can be expected in the concrete. An advantage of using air-entrained cement is that it can be used and batched like normal cement. The air-entrained admixture comes in a liquid form or mixed in the cement. To obtain the proper mix, you should add the admixture at the batch plant.

AGGREGATES

The material combined with cement and water to make concrete is called aggregate. Aggregate makes up 60 to 80 percent of concrete volume. It increases the strength of concrete, reduces the shrinking tendencies of the cement, and is used as an economical filler.

Types

Aggregates are divided into fine (usually consisting of sand) and coarse categories. For most building concrete, the coarse aggregate consists of gravel or crushed stone up to 1 1/2 inches in size. However, in massive structures, such as dams, the coarse aggregate may include natural stones or rocks ranging up to 6 inches or more in size.

Purpose of Aggregates

The large, solid coarse aggregate particles form the basic structural members of the concrete. The voids between the larger coarse aggregate particles are filled by smaller particles. The voids between the smaller particles are filled by still smaller particles. Finally, the voids between the smallest coarse aggregate particles are filled by the largest fine aggregate particles. In turn, the voids between the largest fine aggregate particles are filled by smaller fine aggregate particles, the voids between the smaller fine aggregate particles by still smaller particles, and soon. Finally, the voids between the finest grains are filled with cement. You can see from this that the better the aggregate is graded (that is, the better the distribution of particles sizes), the more solidly all voids will be filled, and the denser and stronger will be the concrete.

The cement and water form a paste that binds the aggregate particles solidly together when it hardens. In a well-graded, well-designed, and well-mixed batch, each aggregate particle is thoroughly coated with the cement-water paste. Each particle is solidly bound to adjacent particles when the cement-water paste hardens.

AGGREGATE SIEVES.— The size of an aggregate sieve is designated by the number of meshes to the linear inch in that sieve. The higher the number, the finer the sieve. Any material retained on the No. 4 sieve can be considered either coarse or fine. Aggregates huger than No. 4 are all course; those smaller are all fines. No. 4 aggregates are the dividing point. The finest coarse-aggregate sieve is the same No. 4 used as the coarsest fine-aggregate sieve. With this exception, a coarse-aggregate sieve is designated by the size of one of its openings. The sieves commonly used are 1 1/2 inches, 3/4 inch, 1/2 inch, 3/8 inch, and No. 4. Any material that passes through the No. 200 sieve is too fine to be used in making concrete.

PARTICLE DISTRIBUTION.— Experience and experiments show that for ordinary building concrete, certain particle distributions consistently seem to produce the best results. For tine aggregate, the recommended distribution of particle sizes from No. 4 to No. 100 is shown in table 6-1.

The distribution of particle sizes in aggregate is determined by extracting a representative sample of the material, screening the sample through a series of sieves ranging in size from coarse to fine, and determining the percentage of the sample retained on each sieve. This procedure is called making a sieve analysis. For example, suppose the total sample weighs 1 pound. Place this on the No. 4 sieve, and shake the sieve until nothing more goes through. If what is left on the sieve weighs 0.05 pound, then 5 percent of the total sample is retained on the No. 4 sieve. Place what passes through on the No. 8 sieve and shake it. Suppose you find that what stays on this sieve weighs 0.1 pound. Since 0.1 pound is 10 percent of 1 pound, 10 percent of the total sample was retained on the No. 8 sieve. The cumulative retained weight is 0.15 pound. By dividing 0.15 by 1.0 pound, you will find that the total retained weight is 15 percent.

The size of coarse aggregate is usually specified as a range between a minimum and a maximum size; for example, 2 inches to No. 4, 1 inch to No. 4,

Table 6-1.—Recommended Distribution of Particle Sizes

SIEVE NUMBER	PERCENT RETAINED ON SQUARE MESH LABORATORY SIEVES
3/8"	0
No. 4	18
No. 8	27
No. 16	20
No. 30	20
No. 50	10
No. 100	4

Table 6-2.—Recommended Maximum and Minimum Particle Sizes

SIZE OF COURSE AGGREGATE, IN INCHES	PERCENTAGES BY WEIGHT PASSING LABORATORY SIEVES HAVING SQUARE OPENINGS										
	4-in.	3 1/2 in.	3-in.	2 1/2 in.	2-in.	1 1/2 in.	1-in.	3/4 in.	1/2 in.	3/8 in.	No. 4
1.5	—	—	—	—	100	95-100	—	35-70	—	10-30	0-5
2	—	—	—	100	95-100	—	35-70	—	10-30	—	0-5
2.5	—	—	100	90-100	—	35-70	—	10-40	—	0-15	0-5
3.5	100	90-100	—	45-80	—	25-50	—	10-30	—	0-15	0-5

2 inches to 1 inch, and so on. The recommended particle size distributions vary with maximum and minimum nominal size limits, as shown in table 6-2.

A blank space in table 6-2 indicates a sieve that is not required in the analysis. For example, for the 2 inch to No. 4 nominal size, there are no values listed under the 4-inch, the 3 1/2-inch, the 3-inch, and the 2 1/2-inch sieves. Since 100 percent of this material should pass through a 2 1/2-inch sieve, there is no need to use a sieve coarser than that size. For the same size designation (that is, 2 inch size aggregate), there are no values listed under the 1 1/2-inch, the 3/4-inch, and the 3/8-inch sieves. Experience has shown that it is not necessary to use these sieves in making this particular analysis.

Quality Standards

Since 66 to 78 percent of the volume of the finished concrete consists of aggregate, it is imperative that the aggregate meet certain minimum quality standards. It should consist of clean, hard, strong, durable particles free of chemicals that might interfere with hydration. The aggregate should also be free of any superfine material, which might prevent a bond between the aggregate and the cement-water paste. The undesirable substances most frequently found in aggregate are dirt, silt, clay, coal, mica, salts, and organic matter. Most of these can be removed by washing. Aggregate can be field-tested for an excess of silt, clay, and the like, using the following procedure:

1. Fill a quart jar with the aggregate to a depth of 2 inches.
2. Add water until the jar is about three-fourths full.
3. Shake the jar for 1 minute, then allow it to stand for 1 hour.
4. If, at the end of 1 hour, more than 1/8 inch of sediment has settled on top of the aggregate, as shown in figure 6-2, the material should be washed.

An easily constructed rig for washing a small amount of aggregate is shown in figure 6-3.

Weak, friable (easily pulverized), or laminated (layered) aggregate particles are undesirable. Especially avoid shale, stones laminated with shale, and most varieties of chart (impure flint-like rock). For most ordinary concrete work, visual inspection is enough to reveal any weaknesses in the coarse

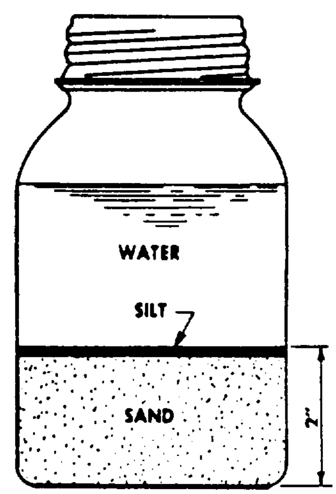

Figure 6-2.—Quart jar method of determining silt content of sand.

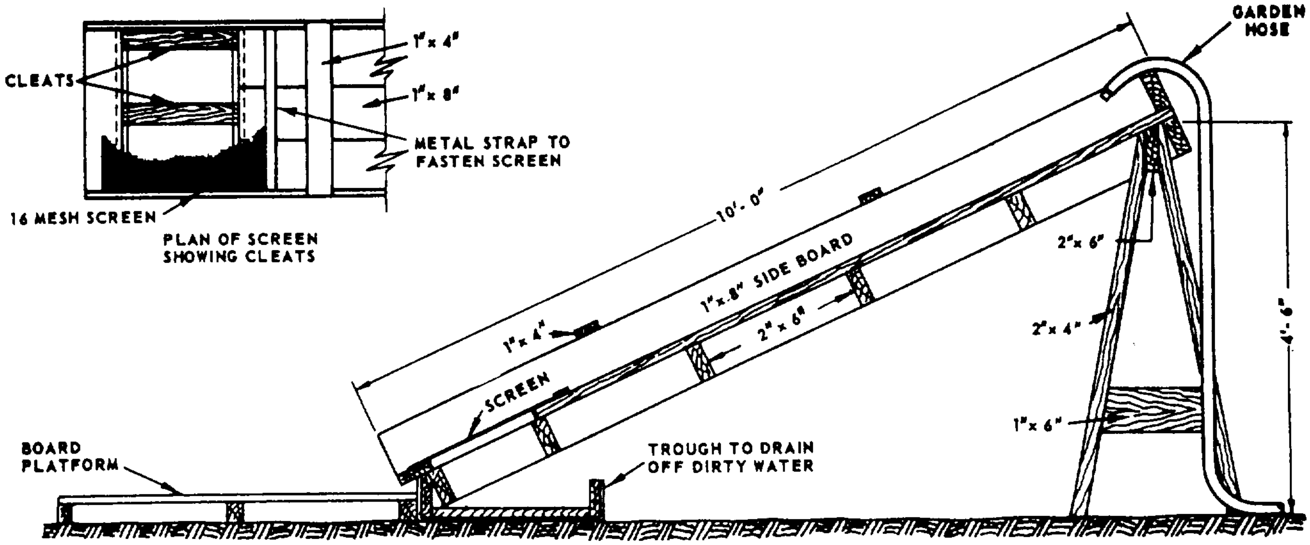

Figure 6-3.-Field-constructed rig for washing aggregate.

aggregate. For work in which aggregate strength and durability are of vital importance, such as paving concrete, aggregate must be laboratory tested.

Handling and Storage

A mass of aggregate containing particles of different sizes has a natural tendency toward segregation. "Segregation" refers to particles of the same size tending to gather together when the material is being loaded, transported, or otherwise disturbed. Aggregate should always be handled and stored by a method that minimizes segregation.

Stockpiles should not be built up in cone shapes, formed by dropping successive loads at the same spot. This procedure causes segregation. A pile should be built up in layers of uniform thickness, each made by dumping successive loads alongside each other.

If aggregate is dropped from a clamshell, bucket, or conveyor, some of the fine material may be blown aside, causing a segregation of fines on the lee side (that is, the side away from the wind) of the pile. Conveyors, clamshells, and buckets should be discharged in contact with the pile.

When a bin is being charged (filled), the material should be dropped from a point directly over the outlet. Material chuted in at an angle or material discharged against the side of a bin will segregate. Since a long drop will cause both segregation and the breakage of aggregate particles, the length of a drop into a bin should be minimized by keeping the bin as full as possible at all times. The bottom of a storage bin should always slope at least 50° toward the central outlet. If the slope is less than 50°, segregation will occur as material is discharged out of the bin.

WATER

The two principal functions of water in a concrete mix are to effect hydration and improve workability. For example, a mix to be poured in forms must contain more water than is required for complete hydration of the cement. Too much water, however, causes a loss of strength by upsetting the wqter-cement ratio. It also causes "water-gain" on the surface-a condition that leaves a surface layer of weak material, called laitance. As previously mentioned, an excess of water also impairs the watertightness of the concrete.

Water used in mixing concrete must be clean and free from acids, alkalis, oils, and organic materials. Most specifications recommend that the water used in mixing concrete be suitable for drinking, should such water be available.

Seawater can be used for mixing unreinforced concrete if there is a limited supply of fresh water. Tests show that the compressive strength of concrete made with seawater is 10 to 30 percent less than that obtained using fresh water. Seawater is not suitable for use in making steel-reinforced concrete because of the risk of corrosion of the reinforcement, particularly in warm and humid environments.

ADMIXTURES

Admixtures include all materials added to a mix other than portland cement, water, and aggregates.

Admixtures are sometimes used in concrete mixtures to improve certain qualities, such as workability, strength, durability, watertightness, and wear resistance. They may also be added to reduce segregation, reduce the heat of hydration, entrain air, and accelerate or retard setting and hardening.

We should note that the same results can often be obtained by changing the mix proportions or by selecting other suitable materials without resorting to the use of admixtures (except air-entraining admixtures when necessary). Whenever possible, comparison should be made between these alternatives to determine which is more economical or convenient. Any admixture should be added according to current specifications and under the direction of the crew leader.

Workability Agents

Materials, such as hydrated lime and bentonite, are used to improve workability. These materials increase the fines in a concrete mix when an aggregate is tested deficient in fines (that is, lacks sufficient fine material).

Air-Entraining Agents

The deliberate adding of millions of minute disconnected air bubbles to cement paste, if evenly diffused, changes the basic concrete mix and increases durability, workability, and strength. The acceptable amount of entrained air in a concrete mix, by volume, is 3 to 7 percent. Air-entraining agents, used with types I, II, or III cement, are derivatives of natural wood resins, animal or vegetable fats, oils, alkali salts of sulfated organic compounds, and water-soluble soaps. Most air-entraining agents are in liquid form for use in the mixing water.

Accelerator

The only accepted accelerator for general concrete work is calcium chloride with not more than 2 percent by weight of the cement being used. This accelerator is added as a solution to the mix water and is used to speed up the strength gain. Although the final strength is not affected, the strength gain for the first 7 days is greatly affected. The strength gain for the first 7 days can be as high as 1,000 pounds per square inch (psi) over that of normal concrete mixes.

Retarders

The accepted use for retarders is to reduce the rate of hydration. This permits the placement and consolidation of concrete before initial set. Agents normally used are fatty acids, sugar, and starches.

CEMENT STORAGE

Portland cement is packed in cloth or paper sacks, each weighing 94 pounds. A 94-pound sack of cement amounts to about 1 cubic foot by loose volume.

Cement will retain its quality indefinitely if it does not come in contact with moisture. If allowed to absorb appreciable moisture in storage, however, it sets more slowly and strength is reduced. Sacked cement should be stored in warehouses or sheds made as watertight and airtight as possible. All cracks in roofs and walls should be closed, and there should be no openings between walls and roof. The floor should be above ground to protect the cement against dampness. All doors and windows should be kept closed.

Sacks should be stacked against each other to prevent circulation of air between them, but they should not be stacked against outside walls. If stacks are to stand undisturbed for long intervals, they should be covered with tarpaulins.

When shed or warehouse storage cannot be provided, sacks that must be stored in the open should be stacked on raised platforms and covered with waterproof tarps. The tarps should extend beyond the edges of the platform to deflect water away from the platform and the cement.

Cement sacks stacked in storage for long periods sometimes acquire a hardness called warehouse pack. This can usually be loosened by rolling the sack around. However, cement that has lumps or is not free flowing should not be used.

CONCRETE MIX DESIGN

LEARNING OBJECTIVE: Upon completing this section, you should be able to calculate concrete mix designs.

Before proportioning a concrete mix, you need information concerning the job, such as size and shapes of structural members, required strength of the concrete, and exposure conditions. The end use of the concrete and conditions at time of placement are additional factors to consider.

INGREDIENT PROPORTIONS

The ingredient proportions for the concrete on a particular job are usually set forth in the specifications under “CONCRETE—General Require-merits.” See table 6-3 for examples of normal

Table 6-3.-Normal Concrete

CLASS OF CONCRETE (FIGURES DENOTE SIZE OF COARSE AGGREGATE IN INCHES)	ESTIMATED 28-DAY COMPRESSIVE STRENGTH (POUNDS PER SQUARE INCH)	CEMENT FACTOR BAGS (94 POUNDS) OF CEMENT PER CUBIC YARD OF CONCRETE FRESHLY MIXED	MAXIMUM WATER (GALLONS) PER BAG (94 POUNDS) OF CEMENT	FINE AGGREGATE RANGE IN PERCENT OF TOTAL AGGREGATE BY WEIGHT	APPROXIMATE WEIGHTS OF SATU-RATED SURFACE-DRY AGGREGATES PER BAG (94 POUNDS) OF CEMENT	
					FINE AGGREGATE POUNDS	COURSE AGGREGATE POUNDS
(1)	(2)	(3)	(4)	(5)	(6)	(7)
B-1	1,500	4.10	9.50	42-52	368	415
B1-1.5	1,500	3.80	9.50	38-48	376	498
B-2	1,500	3.60	9.50	35-45	378	567
B-2.5	1,500	3.50	9.50	33-43	373	609
B-3.5	1,500	3.25	9.50	30-40	378	702
C-1	2,000	4.45	8.75	41-51	329	387
C-1.5	2,000	4.10	8.75	37-47	338	467
C-2	2,000	3.90	8.75	34-44	338	529
C-2.5	2,000	3.80	8.75	32-42	332	565
C-3.5	2,000	3.55	8.75	29-39	334	648
D-0.5	2,500	5.70	7.75	50-60	282	231
D-0.75	2,500	5.30	7.75	45-55	288	288
D-1	2,500	5.05	7.75	40-50	279	341
D-1.5	2,500	4.65	7.75	36-46	287	413
D-2	2,500	4.40	7.75	34-42	288	471
D-2.5	2,500	4.25	7.75	32-40	287	509
D-3.5	2,500	4.00	7.75	29-37	285	578
E-0.5	3,000	6.50	6.75	50-58	238	203
E-0.75	3,000	6.10	6.75	45-53	240	249
E-1	3,000	5.80	6.75	40-48	233	297
E-1.5	3,000	5.35	6.75	36-44	239	359
E-2	3,000	5.05	6.75	33-41	241	410
E-2.5	3,000	4.90	6.75	31-39	238	441
E-3.5	3,000	4.60	6.75	28-36	237	503
F-0.375	3,500	7.70	6.00	56-64	210	140
F-0.5	3,500	7.35	6.00	48-56	198	183
F-0.75	3,500	6.85	6.00	43-51	201	226
F-1	3,500	6.50	6.00	38-46	195	270
F-1.5	3,500	6.00	6.00	34-42	200	325
F-2	3,500	5.70	6.00	31-29	199	369
F-2.5	3,500	5.50	6.00	29-37	197	400
F-3.5	3,500	5.20	6.00	27-35	200	444
G-0.25	4,000	8.95	5.50	100	281	—
G-0.375	4,000	8.40	5.50	55-63	186	129
G-0.5	4,000	8.00	5.50	47-55	175	168
G-0.75	4,000	7.45	5.50	42-50	178	209
G-1	4,000	7.10	5.50	37-45	172	247
G-1.5	4,000	6.55	5.50	33-41	175	299
G-2	4,000	6.20	5.50	30-38	175	340
G-2.5	4,000	6.00	5.50	28-36	173	368
G-3.5	4,000	5.65	5.50	26-34	176	411
H-0.25	5,000	11.50	4.25	100	202	—
H-0.375	5,000	10.80	4.25	53-61	130	98
H-0.5	5,000	10.35	4.25	45-53	121	126
H-0.75	5,000	9.65	4.25	40-48	123	157
H-1	5,000	9.20	4.25	35-43	119	186
H-1.5	5,000	8.45	4.25	31-39	122	228
H-2	5,000	8.00	4.25	28-36	122	260

concrete-mix design according to NAVFAC specifications.

In table 6-3, one of the formulas for 3,000 psi concrete is 5.80 bags of cement per cubic yard, 233 pounds of sand (per bag of cement), 297 pounds of coarse aggregate (per bag of cement), and a water-cement ratio of 6.75 gallons of water to each bag of cement. These proportions are based on the assumption that the inert ingredients are in a saturated surface-dry condition, meaning that they contain all the water they are capable of absorbing, but no additional free water over and above this amount.

We need to point out that a saturated surface-dry condition almost never exists in the field. The amount of free water in the coarse aggregate is usually small enough to be ignored, but the ingredient proportions set forth in the specs must almost always be adjusted to allow for the existence of free water in the fine aggregate. Furthermore, since free water in the fine aggregate increases its measured volume or weight over that of the sand itself, the specified volume or weight of sand must be increased to offset the volume or weight of the water in the sand. Finally, the number of gallons of water used per sack of cement must be reduced to allow for the free water in the sand. The amount of water actually added at the mixer must be the specified amount per sack, less the amount of free water that is already in the ingredients in the mixer.

Except as otherwise specified in the project specifications, concrete is proportioned by weighing and must conform to NAVFAC specifications. (See table 6-3 for normal concrete.)

MATERIAL ESTIMATES

When tables, such as table 6-3, are not available for determining quantities of material required for 1 cubic yard of concrete, a rule of thumb, known as rule 41 or 42, may be used for a rough estimation. According to this rule, it takes either 41 or 42 cubic feet of the combined dry amounts of cement, sand, and aggregates to produce 1 cubic yard of mixed concrete. Rule 41 is used to calculate the quantities of material for concrete when the size of the coarse aggregate is not over 1 inch. Rule 42 is used when the size of the coarse aggregate is not over 2 1/2 inches. Here is how it works.

As we mentioned earlier, a bag of cement contains 94 pounds by weight, or about 1 cubic foot by loose volume. A batch formula is usually based on the number of bags of cement used in the mixing machine.

For estimating the amount of dry materials needed to mix 1 cubic yard of concrete, rules 41 and 42 work in the same manner. The decision on which rule to use depends upon the size of the aggregate. Let's say your specifications call for a 1:2:4 mix with 2-inch coarse aggregates, which means you use rule 42, First, add 1:2:4, which gives you 7. Then compute your material requirements as follows:

$42 \div 7 = 6$ bags, or 6 cu ft of cement;

$6 \times 2 = 12$ cu ft of sand;

$6 \times 4 = 24$ cu ft of coarse aggregates.

Adding your total dry materials, 6 + 12 + 24= 42, so your calculations are correct.

Frequently, you will have to convert volumes in cubic feet to weights in pounds. In converting, multiply the required cubic feet of cement by 94 since 1 cubic foot, or 1 standard bag of cement, weighs 94 pounds. When using rule 41 for coarse aggregates, multiply the quantity of coarse gravel in cubic feet by 105 since the average weight of dry-compacted fine aggregate or gravel is 105 pounds per cubic feet. By rule 42, however, multiply the cubic feet of rock (1-inch-size coarse aggregate) by 100 since the average dry-compacted weight of this rock is 100 pounds per cubic foot.

A handling-loss factor is added in ordering materials for jobs. An additional 5 percent of materials is added for jobs requiring 200 or more cubic yards of concrete, and 10 percent is added for smaller jobs. This loss factor is based on material estimates after the requirements have been calculated. Additional loss factors may be added where conditions indicate the necessity for excessive handling of materials before batching.

Measuring Water

The water-measuring controls on a machine concrete mixer are described later in this chapter. Water measurement for hand mixing can be done with a 14-quart bucket, marked off on the inside in gallons, half-gallons, and quarter-gallons.

Never add water to the mix without carefully measuring the water, and always remember that the amount of water actually placed in the mix varies according to the amount of free water that is already in the aggregate. This means that if the aggregate is wet by a rainstorm, the proportion of water in the mix may have to be changed.

Measuring Aggregate

The accuracy of aggregate measurement by volume depends upon the accuracy with which the amount of "bulking," caused by moisture in the aggregate, can be determined. The amount of bulking varies not only with different moisture contents but also with different gradations. Fine sand, for example, is bulked more than coarse sand by the same moisture content. Furthermore, moisture content itself varies from time to time, and a small variation causes a large change in the amount of bulking. For these and other reasons, aggregate should be measured by weight rather than by volume whenever possible.

To make grading easier, to keep segregation low, and to ensure that each batch is uniform, you should store and measure coarse aggregate from separate piles or hoppers. The ratio of maximum to minimum particle size should not exceed 2:1 for a maximum nominal size larger than 1 inch. The ratio should not exceed 3:1 for a maximum nominal size smaller than 1 inch. A mass of aggregate with a nominal size of 1 1/2 inches to 1/4 inch, for example, should be separated into one pile or hopper containing 1 1/2-inch to 3/4-inch aggregate, and another pile or hopper containing 3/4-inch to 1/4-inch aggregate. A mass with a nominal size of 3 inches to 1/4 inch should be separated into one pile or hopper containing 3-inch to 1 1/2-inch aggregate, another containing 1 1/2-inch to 3/4-inch aggregate, and a third containing 3/4-inch to 1/4-inch aggregate.

Water-Cement Ratio

The major factor controlling strength, everything else being equal, is the amount of water used per bag of cement. Maximum strength is obtained by using just the amount of water, and no more, required for the complete hydration of the cement. As previously mentioned, however, a mix of this type maybe too dry to be workable. Concrete mix always contains more water than the amount required to attain maximum strength. The point for you to remember is that the strength of concrete decreases as the amount of extra water increases.

The specified water-cement ratio is the happy medium between the maximum possible strength of the concrete and the necessary minimum workability requirements. The strength of building concrete is expressed in terms of the compressive strength in pounds per square inch (psi) reached after a 7- or 28-day set. This is usually referred to as "probable average 7-day strength" and "probable average 28-day strength."

SLUMP TESTING

Slump testing is a means of measuring the consistency of concrete using a "slump cone." The cone is made of galvanized metal with an 8-inch-diameter base, a 4-inch-diameter top, and a 12-inch height. The base and the top are open and parallel to each other and at right angles to the axis of the cone (figure 6-4). A tamping rod 5/8 inch in diameter and 24 inches long is also needed. The tamping rod should be smooth and bullet-pointed. Do not use a piece of reinforcing bar (rebar).

Samples of concrete for test specimens are taken at the mixer or, in the case of ready-mixed concrete, from the transportation vehicle during discharge. The sample of concrete from which test specimens are made should be representative of the entire batch. Such samples are obtained by repeatedly passing a scoop or pail through the discharging stream of concrete, starting the sampling operation at the beginning of discharge, and repeating the operation until the entire batch is discharged. To counteract segregation when a sample must be transported to a test site, the concrete should be remixed with a shovel until it is uniform in appearance. The job location from which the sample was taken should be noted for future reference. In the case of paving concrete,

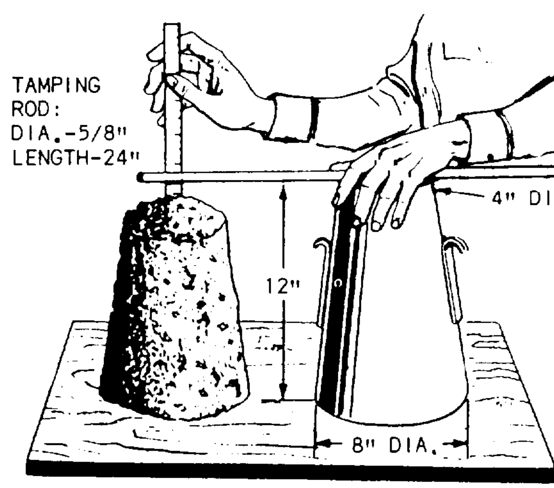

Figure 6-4.-Measurement of slump.

samples may be taken from the batch immediately after depositing it on the subgrade. At least five samples should be taken at different times, and these samples should be thoroughly mixed to form the test specimen.

When making a slump test, dampen the cone and place it on a flat, moist, nonabsorbent surface, From the sample of concrete obtained, immediately fill the cone in three layers, each approximately one-third the volume of the cone. In placing each scoop full of concrete in the cone, move the scoop around the edge of the cone as the concrete slides from the scoop. This ensures symmetrical distribution of concrete within the cone. Each layer is then "rodded in" with 25 strokes. The strokes should be distributed uniformly over the cross section of the cone and penetrate into the underlying layer. The bottom layer should be rodded throughout its depth.

If the cone becomes overfilled, use a straightedge to strike off the excess concrete flush with the top. The cone should be immediately removed from the concrete by raising it carefully in a vertical direction. The slump should be measured immediately after removing the cone. You determine the slump by measuring the difference between the height of the cone and the height of the specimen (figure 6-4). The slump should be recorded in terms of inches of subsidence of the specimen during the test.

After completing the slump measurement, gently tap the side of the mix with the tamping rod. The behavior of the concrete under this treatment is a valuable indication of the cohesiveness, workability, and placability of the mix. In a well-proportioned mix, tapping only causes it to slump lower. It doesn't crumble apart or segregate by the dropping of larger aggregate particles to a lower level in the mix. If the concrete crumbles apart, it is oversanded. If it segregates, it is undersanded.

WORKABILITY

A mix must be workable enough to fill the form spaces completely, with the assistance of a reasonable amount of shoveling, spading, and vibrating. Since a fluid or "runny" mix does this more readily than a dry or "stiff" mix, you can see that workability varies directly with fluidity. The workability of a mix is determined by the slump test. The amount of the slump, in inches, is the measure of the concrete's workability—the more the slump, the higher the workability.

The slump can be controlled by a change in any one or all of the following: gradation of aggregates, proportion of aggregates, or moisture content. If the moisture content is too high, you should add more cement to maintain the proper water-cement ratio.

The desired degree of workability is attained by running a series of trial batches, using various amounts of fine to coarse aggregate, until a batch is produced that has the desired slump. Once the amount of increase or decrease in fines required to produce the desired slump is determined, the aggregate proportions, not the water proportion, should be altered in the field mix to conform. If the water proportion were changed, the water-cement ratio would be upset.

Never yield to the temptation to add more water without making the corresponding adjustment in the cement content. Also, make sure that crewmembers who are spreading a stiff mix by hand do not ease their labors by this method without telling you.

As you gain experience, you will discover that adjustments in workability can be made by making very minor changes in the amount of fine or coarse aggregate. Generally, everything else remaining equal, an increase in the proportion of fines stiffens a mix, whereas an increase in the proportion of coarse loosens a mix.

NOTE

Before you alter the proportions set forth in a specification, you must find out from higher authority whether you are allowed to make any such alterations and, if you are, the permissible limits beyond which you must not go.

GROUT

As previously mentioned, concrete consists of four essential ingredients: water, cement, sand, and coarse aggregate. The same mixture without aggregate is mortar. Mortar, which is used chiefly for bonding masonry units together, is discussed in a later chapter. Grout refers to a water-cement mixture called neat-cement grout and to a water-sand-cement mixture called sand-cement grout. Both mixtures are used to plug holes or cracks in concrete, to seal joints, to fill spaces between machinery bedplates and concrete foundations, and for similar plugging or sealing purposes. The consistency of grout may range from stiff (about 4 gallons of water per sack of cement) to fluid (as many as 10 gallons of water per sack of cement), depending upon the nature of the grouting job at hand.

BATCHING

When bagged cement is used, the field mix proportions are usually given in terms of designated amounts of fine and coarse aggregate per bag (or per 94 pounds) of cement. The amount of material that is mixed at a time is called a batch. The size of a batch is usual] y designated by the number of bags of cement it contains, such as a four-bag batch, a six-bag batch, and so forth.

The process of weighing out or measuring out the ingredients for a batch of concrete is called batching. When mixing is to be done by hand, the size of the batch depends upon the number of persons available to turn it with hand tools. When mixing is to be done by machine, the size of the batch depends upon the rated capacity of the mixer. The rated capacity of a mixer is given in terms of cubic feet of mixed concrete, not of dry ingredients.

On large jobs, the aggregate is weighed out in an aggregate batching plant (usually shortened to "batch plant"), like the one shown in figure 6-5. Whenever possible, a batch plant is located near to and used in conjunction with a crushing and screening plant. In a crushing and screening plant, stone is crushed into various particle sizes, which are then screened into separate piles. In a screening plant, the aggregate in its natural state is screened by sizes into separate piles.

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Figure 6-5.-Aggregate batching plant

The batch plant, which is usually portable and can be taken apart and moved from site to site, is generally set up adjacent to the pile of screened aggregate. The plant may include separate hoppers for several sizes of fine and coarse aggregates, or only one hopper for fine aggregate and another for coarse aggregate. It may have one or more divided hoppers, each containing two or more separate compartments for different sizes of aggregates.

Each storage hopper or storage hopper compartment can be discharged into a weigh box, which can, in turn, be discharged into a mixer or a batch truck. When a specific weight of aggregate is called for, the operator sets the weight on a beam scale. The operator then opens the discharge chute on the storage hopper. When the desired weight is reached in the weigh box, the scale beam rises and the operator closes the storage hopper discharge chute. The operator then opens the weigh box discharge chute, and the aggregate discharges into the mixer or batch truck. Batch plant aggregate storage hoppers are usually loaded with clamshell-equipped cranes.

The following guidelines apply to the operation of batch plants:

- All personnel working in the batch plant area should wear hard hats at all times.
- While persons are working in conveyor line areas, the switches and controls should be secured and tagged so that no one can engage them until all personnel are clear.
- When hoppers are being loaded, personnel should stay away from the area of falling aggregate.
- The scale operator should be the only person on the scale platform during batching operations.
- Housekeeping of the charging area is important. Personnel should do everything possible to keep the area clean and free of spoiled material or overflow.
- Debris in aggregate causes much of the damage to conveyors. Keep the material clean at all times.

- When batch operations are conducted at night, good lighting is a must.
- Personnel working in batch plants should use good eye hygiene. Continual neglect of eye care can have serious consequences.

MIXING CONCRETE

LEARNING OBJECTIVE: Upon completing this section, you should be able to determine methods and mixing times of concrete.

Concrete is mixed either by hand or machine. No matter which method is used, you must follow well-established procedures if you expect finished concrete of good quality. An oversight in proper concrete mixing, whether through lack of competence or inattention to detail, cannot be corrected later.

MIXING BY HAND

A batch to be hand mixed by a couple of crewmembers should not be much larger than 1 cubic yard. The equipment required consists of a watertight metal or wooden platform, two shovels, a metal-lined measuring box, and a graduated bucket for measuring the water.

The mixing platform does not need to be made of expensive materials. It can be an abandoned concrete slab or concrete parking lot that can be cleaned after use. A wooden platform having tight joints to prevent the loss of paste may be used. Whichever surface is used, you should ensure that it is cleaned prior to use and level.

Let’s say your batch consists of two bags of cement, 5.5 cubic feet of sand, and 6.4 cubic feet of coarse aggregate. Mix the sand and cement together first, using the following procedure:

1. Dump 3 cubic feet of sand on the platform first, spread it out in a layer, and dump a bag of cement over it.

2. Spread out the cement and dump the rest of the sand (2.5 cubic feet) over it.

3. Dump the second sack of cement on top of the lot.

This use of alternate layers of sand and cement reduces the amount of shoveling required for complete mixing.

Personnel doing the mixing should face each other from opposite sides of the pile and work from the outside to the center. They should turn the mixture as many times as is necessary to produce a uniform color throughout. When the cement and sand are completely mixed, the pile should be leveled off and the coarse material added and mixed by the same turning method.

The pile should next be troughed in the center. The mixing water, after being carefully measured, should be poured into the trough. The dry materials should then be turned into the water, with great care taken to ensure that none of the water escapes. When all the water has been absorbed, the mixing should continue until the mix is of a uniform consistency. Four complete turnings are usually required.

MIXING BY MACHINE

The size of a concrete mixer is designated by its rated capacity. As we mentioned earlier, the capacity is expressed in terms of the volume of mixed concrete, not of dry ingredients the machine can mix in a single batch. Rated capacities run from as small as 2 cubic feet to as large as 7 cubic yards (189 cubic feet). In the Naval Construction Forces (NCFs), the most commonly used mixer is the self-contained Model 16-S (figure 6-6) with a capacity of 16 cubic feet (plus a 10-percent overload).

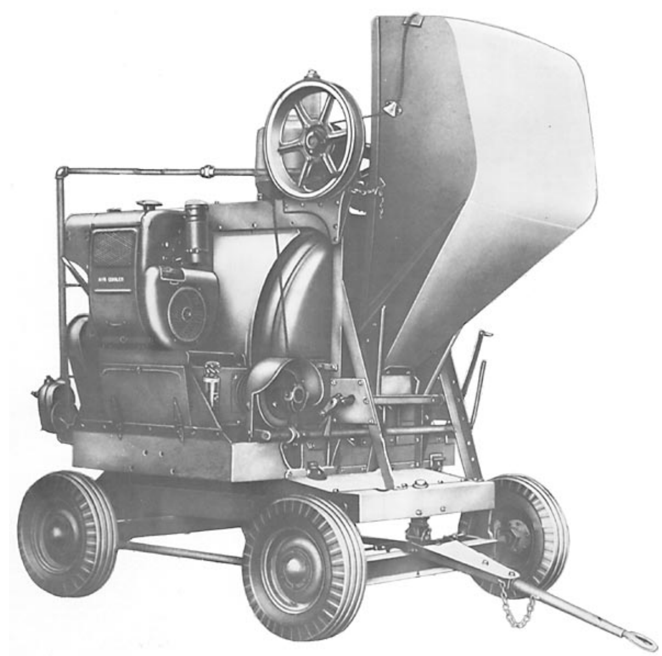

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Figure 6-6.-Model 16-S concrete mixer.

The production capacity of the 16-S mixer varies between 5 and 10 cubic yards per hour, depending on the efficiency of the personnel. Aggregate larger than 3 inches will damage the mixer. The mixer consists of a frame equipped with wheels and towing tongue (for easy movement), an engine, a power loader skip, mixing drum, water tank, and an auxiliary water pump. The mixer may be used as a central mixing plant.

Charging the Mixer

Concrete mixers may be charged by hand or with the mechanical skip. Before loading the mechanical skip, remove the towing tongue. Then cement, sand, and gravel are loaded and dumped into the mixer together while the water runs into the mixing drum on the side opposite the skip. A storage tank on top of the mixer measures the mixing water into the drum a few seconds before the skip dumps. This discharge also washes down the mixer between batches. The coarse aggregate is placed in the skip first, the cement next, and the sand is placed on top to prevent excessive loss of cement as the batch enters the mixer.

Mixing Time

It takes a mixing machine having a capacity of 27 cubic feet or larger 1 1/2 minutes to mix a 1-cubic yard batch. Another 15 seconds should be allowed for each additional 1/2 cubic yard or fraction thereof. The water should be started into the drum a few seconds before the skip begins to dump, so that the inside of the drum gets a washout before the batched ingredients go in. The mixing period should be measured from the time all the batched ingredients are in, provided that all the water is in before one-fourth of the mixing time has elapsed. The time elapsing between the introduction of the mixing water to the cement and aggregates and the placing of the concrete in the forms should not exceed 1 1/2 hours.

Discharging the Mixer

When the material is ready for discharge from the mixer, the discharge chute is moved into place to receive the concrete from the drum of the mixer. In some cases, stiff concrete has a tendency to carry up to the top of the drum and not drop down in time to be deposited on the chute. Very wet concrete may not carry up high enough to be caught by the chute. This condition can be corrected by adjusting the speed of the mixer. For very wet concrete, the speed of the drum should be increased. For stiff concrete, the drum speed should be slowed down,

Cleaning and Maintaining the Mixer

The mixer should be cleaned daily when it is in continuous operation or following each period of use if it is in operation less than a day. If the outside of the mixer is kept coated with oil, the cleaning process can be speeded up. The outside of the mixer should be washed with a hose, and all accumulated concrete should be knocked off. If the blades of the mixer become worn or coated with hardened concrete, the mixing action will be less efficient. Badly worn blades should be replaced. Hardened concrete should not be allowed to accumulate in the mixer drum. The mixer drum must be cleaned out whenever it is necessary to shut down for more than 1 1/2 hours. Place a volume of coarse aggregate in the drum equal to one-half of the capacity of the mixer and allow it to revolve for about 5 minutes. Discharge the aggregate and flush out the drum with water. Do not pound the discharge chute, drum shell, or the skip to remove aggregate or hardened concrete. Concrete will readily adhere to the dents and bumps created. For complete instructions on the operation, adjustment, and maintenance of the mixer, study the manufacturer's manual.

All gears, chains, and rollers of mixers should be properly guarded. All moving parts should be cleaned and properly serviced to permit safe performance of the equipment. When the mixer drum is being cleaned, the switches must be open, the throttles closed, and the control mechanism locked in the OFF position. The area around the mixer must be kept clear.

Skip loader cables and brakes must be inspected frequently to prevent injuries caused by falling skips. When work under an elevated skip is unavoidable, you must shore up the skip to prevent it from falling in the event that the brake fails or is accidentally released. The mixer operator must never lower the skip without first making sure that there is no one underneath.

Dust protection equipment must be issued to the crew engaged in handling cement, and the crew must wear the equipment when so engaged. Crewmembers should stand with their backs to the wind, whenever possible. This helps prevent cement and sand from being blown into their eyes and faces.

HANDLING AND TRANSPORTING CONCRETE

When ready-mixed concrete is carried by an ordinary type of carrier (such as a wheelbarrow or buggy), jolting of the carrier increases the natural tendency of the concrete to segregate. Carriers should therefore be equipped with pneumatic tires whenever possible, and the surface over which they travel should be as smooth as possible.

A long free fall also causes concrete to segregate. If the concrete must be discharged at a level more than 4 feet above the level of placement, it should be dumped into an “elephant trunk” similar to the one shown in figure 6-7.

Segregation also occurs when discharged concrete is allowed to glance off a surface, such as the side of a form or chute. Wheelbarrows, buggies, and conveyors should discharge so that the concrete falls clear.

Concrete should be transported by chute only for short distances. It tends to segregate and dry out when handled in this manner. For a mix of average workability y, the best slope for a chute is about 1 foot of rise to 2 or 3 feet of run. A steeper slope causes segregation, whereas a flatter slope causes the concrete to run slowly or not at all. The stiffer the mix, the steeper the slope required. All chutes and spouting used in concrete pours should be clean and well-supported by proper bracing and guys.

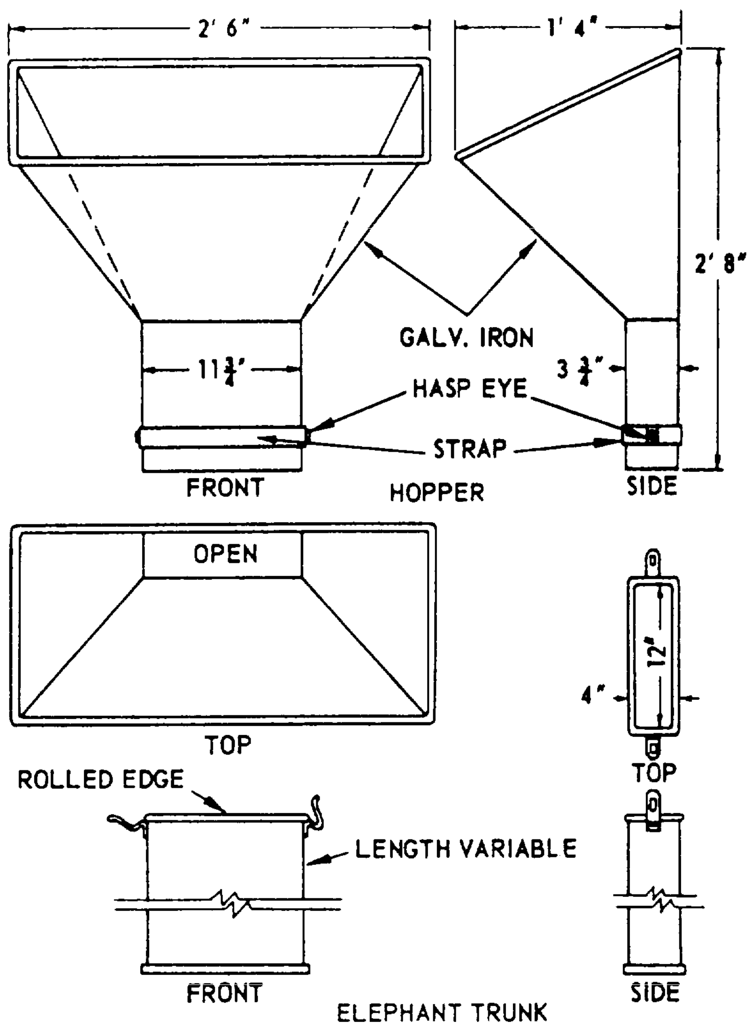

Figure 6-7.-Chute, or downpipe used to check free fall of concrete.

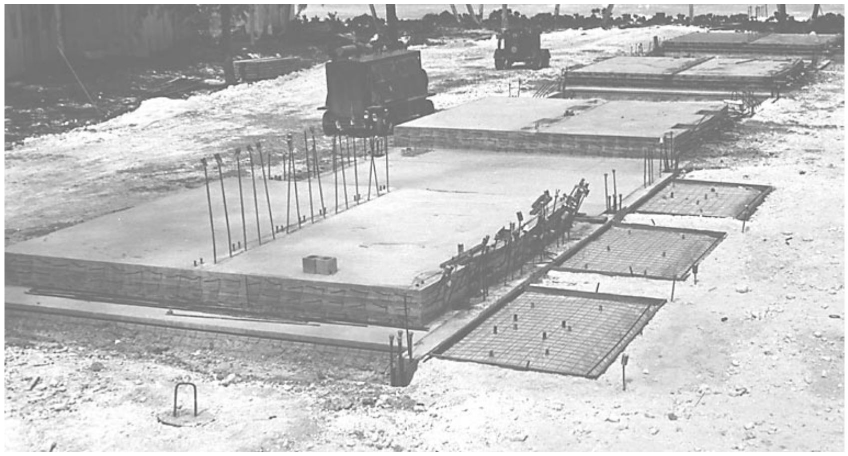

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Figure 6-8.-Precast wall panels in stacks of three each.

When spouting and chutes run overhead, the area beneath must be cleared and barricaded during placing. This eliminates the concrete or possible collapse.

READY-MIXED CONCRETE

On some jobs, such as large danger of falling highway jobs, it is possible to use a batch plant that contains its own mixer. A plant of this type discharges ready-mixed concrete into transit mixers, which haul it to the construction site. The truck carries the mix in a revolving chamber much like the one on a mixer. Keeping the mix agitated in route prevents segregation of aggregate particles. A ready-mix plant is usually portable so that it can follow the job along. It must be certain, of course, that a truck will be able to deliver the mix at the site before it starts to set. Discharge of the concrete from the drum should be completed within 1 1/2 hours.

TRANSIT-MIXED CONCRETE

By transit-mixing, we refer to concrete that is mixed, either wet or dry, en route to a job site. A transit-mix truck carries a mixer and a water tank from which the driver can, at the proper time, introduce the required amount of water into the mix. The truck picks up the dry ingredients at the batch plant, together with a slip which tells how much water is to be introduced to the mix upon arrival at the site. The mixer drum is kept revolving in route and at the job site so that the dry ingredients do not segregate. Transit-mix trucks are part of the battalion's equipment inventory and are widely used on all but the smallest concrete jobs assigned to a battalion.

PRECAST AND TILT-UP CONCRETE

LEARNING OBJECTIVE: Upon completing this section, you should be able to determine projects suitable for and lifting methods necessary for precast and tilt-up construction.

Concrete cast in the position it is to occupy in the finished structure is called cast-in-place concrete. Concrete cast and cured elsewhere is called precast concrete. Tilt-up concrete is a special type of precast concrete in which the units are tilted up and placed using cranes or other types of lifting devices.

Wall construction, for example, is frequently done with precast wall panels originally cast horizontally (sometimes one above the other) as slabs. This method has many advantages over the conventional method of casting in place in vertical wall forms. Since a slab form requires only edge forms and a single surface form, the amount of formwork and form materials required is greatly reduced. The labor involved in slab form concrete casting is much less than that involved in filling a high wall form. One side of a precast unit cast as a slab maybe finished by hand to any desired quality of finishing. The placement of reinforcing steel is much easier in slab forms, and it is easier to attain thorough filling and vibrating. Precasting of wall panels as slabs may be expedited by mass production methods not available when casting in place. Relatively light panels for concrete walls are precast as slabs (figure 6-8). The panels are set in

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Figure 6-9.-Precast panels being erected by use of crane and spreader bars.

place by cranes, using spreader bars (figure 6-9). Figure 6-10 shows erected panels in final position

CASTING

The casting surface is very important in making with precast concrete panels. In this section, we will cover two common types: earth and concrete. Regardless of which method you use, however, a slab must be cast in a location that will permit easy removal and handling.

Castings can be made directly on the ground cement poured into forms. These "earth" surfaces are

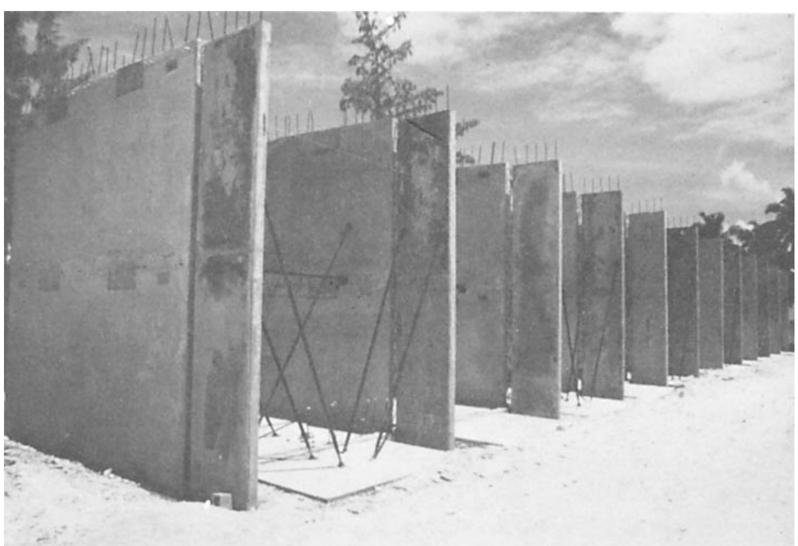

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Figure 6-10.-Precast panels in position.

economical but only last for a couple of concrete pours. Concrete surfaces, since they can be reused repeatedly, are more practical.

When building casting surfaces, you should keep the following points in mind:

- The subbase should be level and properly compacted.

- The slab should be at least 6 inches thick and made of 3,000 psi or higher reinforced concrete. Large aggregate, 2 1/2 inches to 3 inches maximum, may be used in the casting slabs.

- If pipes or other utilities are to be extended up through the casting slab at a later date, they should be stopped below the surface and the openings temporarily closed. For wood, cork, or plastic plugs, fill almost to the surface with sand and top with a thin coat of mortar that is finished flush with the casting surface.

- It is important to remember that any imperfections in the surface of the casting slab will show up on the cast panels. When finishing the casting slab, you must ensure there is a flat, level, and smooth surface without humps, dips, cracks, or gouges. If possible, cure the casting surface keeping it covered with water (pending). However, if a curing compound or surface hardener is used, make sure it will not conflict with the later use of bond-breaking agents.

FORMS

The material most commonly used for edge forms is 2-by lumber. The lumber must be occasionally replaced, but the steel or aluminum angles and charnels may be reused many times. The tops of the forms must be in the same plane so that they maybe used for screeds. They must also be well braced to remain in good alignment.

Edge forms should have holes in them for rebar or for expansion/contraction dowels to protrude. These holes should be 1/4 inch larger in diameter than the bars. At times, the forms are spliced at the line of these bars to make removal easier.

The forms, or rough bucks, for doors, windows, air-conditioning ducts, and so forth, are set before the steel is placed and should be on the same plane as the edge forms.

BOND-BREAKING AGENTS

Bond-breaking agents are one of the most important items of precast concrete construction. The most important requirement is that they must break the bond between the casting surface and the cast panel. Bond-breaking agents must also be economical, fast drying, easily applied, easily removed, or leave a paintable surface on the cast panel, if desired. They are broken into two general types: sheet materials and liquids.

There are many commercially available bond-breaking agents available. You should obtain the type best suited for the project and follow the manufacturer's application instructions. If commercial bond-breaking agents are not available, several alternatives can be used.

- Paper and felt effectively prevent a bond with a casting surface, but usually stick to the cast panels and may cause asphalt stains on the concrete.

- When oiled, plywood, fiberboard, and metal effectively prevent a bond and can be used many times. The initial cost, however, is high and joint marks are left on the cast panels.

- Canvas gives a very pleasing texture and is used where cast panels are lifted at an early stage. It should be either dusted with cement or sprinkled with water just before placing the concrete.

- Oil gives good results when properly used, but is expensive. The casting slab must be dry when the oil is applied, and the oil must be allowed to absorb before the concrete is placed. Oil should not be used if the surface is to be painted, and crankcase oil should never be used.

- Waxes, such as spirit wax (paraffin) and ordinary floor wax, give good-to-excellent results. One mixture that may be used is 5 pounds of paraffin mixed with 1 1/2 gallons of light oil or kerosene. The oil must be heated to dissolve the paraffin.

- Liquid soap requires special care to ensure that an excess amount is not used or the surface of the cast panel will be sandy.

Materials should be applied after the side forms are in place and the casting slab is clean but **before** any reinforcing steel is placed. To ensure proper adhesion of the concrete, keep all bond-breaking materials off the reinforcing steel.

REINFORCEMENTS AND INSERTS

Reinforcing bars (rebar) should be assembled into mats and placed into the forms as a unit. This allows for rapid assembly on a jig and reduces walking on the casting surface, which has been treated with the bond-breating agent.

Extra rebars must be used at openings. They should be placed parallel to and about 2 inches from the sides of openings or placed diagonally across the corners of openings.

The bars may be suspended by conventional methods, such as with high chairs or from members laid across the edge forms. However, high chairs should not be used if the bottom of the cast panel is to be a finished surface. Another method is to first place half the thickness of concrete, place the rebar mat, and then complete the pour. However, this method must be done quickly to avoid a cold joint between the top and bottom layers.

When welded wire fabric (WWF) is used, dowels or bars must still be used between the panels and columns. WWF is usually placed in sheets covering the entire area and then clipped along the edges of the openings after erection.

If utilities are going to be flush-mounted or hidden, pipe, conduit, boxes, sleeves, and so forth should be put into the forms at the same time as the reinforcing steel. If the utilities pass from one cast panel to another, the connections must be made after the panels are erected but before the columns are poured. If small openings are to go through the panel, a greased pipe sleeve is the easiest method of placing an opening in the form. For larger openings, such as air-conditioning ducts, forms should be made in the same reamer as doors or windows.

After rebar and utilities have been placed, all other inserts should be placed. These will include lifting and bracing inserts, anchor bolts, welding plates, and so forth. You need to make sure these items are firmly secured so they won't move during concrete placement or finishing.

POURING, FINISHING, AND CURING

With few exceptions, pouring cast panels can be done in the same manner as other pours. Since the panels are poured in a horizontal position, a stiffer mix can be used. A minimum of six sacks of cement per cubic yard with a maximum of 6 gallons of water per sack of cement should be used along with well-graded aggregate. As pointed out earlier, though, you will have to reduce the amount of water used per sack of cement to allow for the free water in the sand. Large aggregate, up to 1 1/2 inches in diameter, may be used effectively. The concrete should be worked into place by spading or vibration, and extra care must be taken to prevent honeycomb around outer edges of the panel.

Normal finishing methods should be used, but many finishing styles are available for horizontally cast panels. Some finishing methods include patterned, colored, exposed aggregate, broomed, floated, or steel-troweled. Regardless of the finish used, finishers must be cautioned to do the finishing of all panels in a uniform manner. Spots, defects, uneven brooming, or troweling, and so forth will be highly visible when the panels are erected.

Without marring the surface, curing should be started as soon as possible after finishing. Proper curing is important, so cast panels should be cured just like any other concrete to achieve proper strength. Curing compound, if used, prevents bonding with other concrete or paint.

LIFTING EQUIPMENT AND ATTACHMENTS

Tilt-up panels can be set up in many different ways and with various kinds of power equipment. The choice depends upon the size of the job. Besides the equipment, a number of attachments are used.

Equipment

The most popular power equipment is a crane. But other equipment used includes a winch and an A frame, used either on the ground or mounted on a truck. When a considerable number of panels are ready for tilting at one time, power equipment speeds up the job.

Attachments

Many types of lifting attachments are used to lift tilt-up panels. Some of these attachments are locally made and are called hairpins; other types are available commercially. Hairpin types are made on the job site from rebar. These are made by making 180° bends in the ends of two vertical reinforcing bars. The hairpins are then placed in the end of the panel before the concrete is poured. These lifting attachments must protrude from the top of the form for attaching the lifting chains or cables, but go deep enough in the panel form so they won't pull out.

Among the commercial types of lifting attachments, you will find many styles with greater lifting capacities that are more dependable than hairpins if properly installed. These are used with lifting plates. For proper placement of lifting inserts, refer to the plans or specs.

Spreader Bars

Spreader bars (shown in figure 6-9) may be permanent or adjustable, but must be designed and made according to the heaviest load they will carry plus a safety factor. They are used to distribute the lifting stresses evenly, reduce the lateral force applied by slings, and reduce the tendency of panels to bow.

POINT PICKUP METHODS

Once the concrete has reached the desired strength, the panels are ready to be lifted. The strength of the inserts is governed by the strength of the concrete.

CAUTION

An early lift may result in cracking the panel, pulling out the insert, or total concrete failure. The time taken to wait until the concrete has reached its full strength prevents problems and minimizes the risk of injury.

There are several different pickup methods. The following are just some of the basics. Before using these methods on a job, make sure that you check plans and specs to see if these are stated there. Figure 6-11 shows four different pickup methods: 2, 2-2, 4-4, and 2-2-2.

The 2-point pickup is the simplest method, particularly for smaller panels. The pickup cables or chains are fastened directly from the crane hook or spreader bar to two pickup points on or near the top of the precast panel.

The 2-2 point pickup is a better method and is more commonly used. Variations of the 2-2 are 4-4 and 2-2-2, or combinations of pickup points as designated in the job site specifications. These methods use a combination of spreader bars, sheaves, and equal-length cables. The main purpose is to distribute the lifting stresses throughout the panel during erection. Remember, the cables must be long enough to allow ample clearance between the top of the panel and the sheaves or spreader bar.

ERECTING, BRACING, AND JOINTING PANELS

Erecting is an important step in the construction phase of the project. Before you start the erecting phase and for increased safety, you should make sure that all your tools, equipment, and braces are in proper working order. All personnel must be well informed and the signalman and crane operator understand and agree on the signals to be used. During the erection of the panels, make sure that the signalman and line handler are not under the panel and that all unnecessary personnel and equipment are away from the lifting area. After the erection is done, make sure that all panels are properly braced and secured before unhooking the lifting cables.

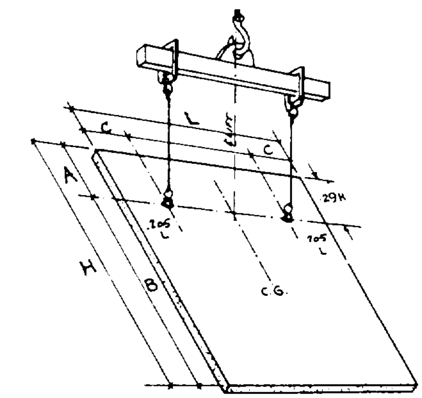
Bracing is an especially important step. After all the work of casting and placing the panels, you want them to stay in place. The following are some steps to take before lifting the panels:

- Install the brace inserts into the panels during casting if possible.
- Install the brace inserts into the floor slab either during pouring or the day before erection.
- Install solid brace anchors before the day of erection.
- If brace anchors must be set during erection, use a method that is fast and accurate.

Although there are several types of bracing, pipe or tubular braces are the most common. They usually have a turnbuckle welded between sections for adjustment. Some braces are also made with telescoping sleeves for greater adaptability. Figure 6-10 shows tube-type braces used to hold up panels. Cable braces are normally used for temporary bracing and for very tall panels. Their flexibility and tendency to stretch, however, make them unsuitable for most projects. Wood bracing is seldom used except for low, small panels or for temporary bracing,

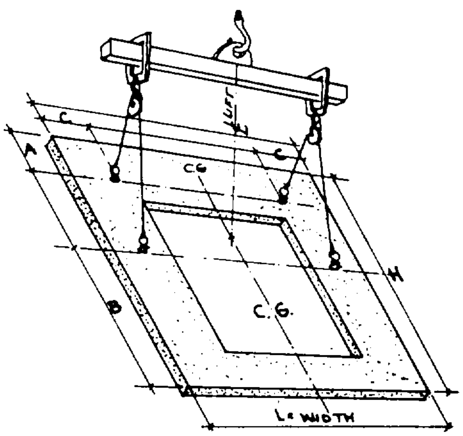
Jointing the panels is simple. Just tie all the panels together, covering the gap between them. You can weld, bolt, or pour concrete columns or beams. Steps used to tie the panels should be stated in the plans and specs.

TWO POINT PICKUP IS BEST SUITED TO WALL PANELS 10' TO 18' IN HEIGHT, AND UP TO 18' IN WIDTH FOR PANELS 5" TO 8" IN PANEL THICKNESS.

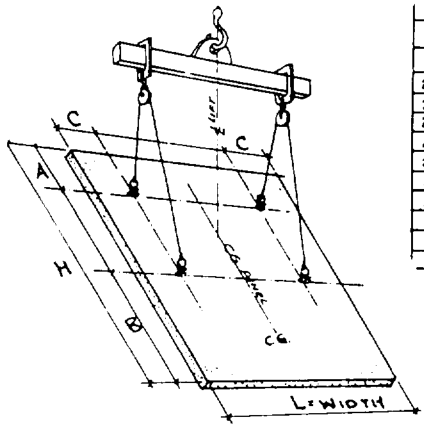


TRIAL POINTS			
H	A	L	C
8'	2'-3"	14'	2'-10"
10'	2'-10"	15'	3'-1"
12'	3'-6"	16'	3'-4"
14	4'-1"	17'	3'-6"
16'	4'-7"	18'	3'-8"
18'	5'-0"	19'	3'-10"
20'	5'-2"	20'	4'-1"

TRUCK DOOR 2-2 PICKUP TRIAL LOCATIONS				
H	A	B	L	C
18'	3'-0"	7'-10"	14'	2'-10"
20'	3'-3"	8'-6"	16'	3'-4"
22'	3'-7"	9'-6"	18'	3'-8"
24'	3'-10"	10-6"	19'	3'-10"
26	4'-0"	11'-6"	20'	4'-1"
27	4'-3"	12'-0"	21'	4'-4"
28	4'-6"	12'-6"	22'	4'-6"
29	4'-9"	12'-10"	23'	4'-8"
30	5'-0"	13'-1"	24'	4'-11"



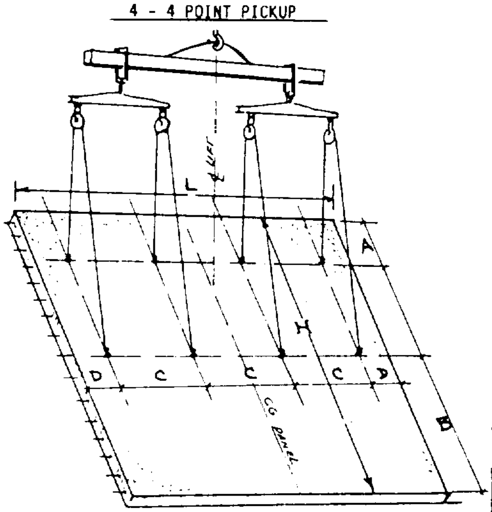
2 - 2 POINT PICKUP



2-2 POINT PICKUP TRIAL LOCATIONS				
H	A	B	L	C
18'	3'-3"	7'-7"	12'	2'-6"
20'	3'-7"	8'-4"	14'	2-10"
22'	3'-11"	9'-3"	15'	3'-1"
23'	4-2"	9'-7"	16'	3'-4"
24'	4'-4"	10'-1"	17'	3'-6"
25'	4'-6"	10'-6"	18'	3'-8"
26'	4-8"	11'-0"	19'	3'-10"
27'	4'-10"	11'-4"	20'	4'-1"
28'	5'-0"	11'-9"	21'	4'-4"
29'	5'-2"	12-2"	22'	4'-6"
30'	5'-4"	12'-7"	23'	4'-8"

2-2-2 POINT PICKUP TRIAL LOCATIONS				
H	A	B	L	C
30	4'-2½"	9'-7"	16'	3'-4"
32	4'-6"	10'-3"	18'	3'-8"
34	4-10"	10'-10"	19'	3'-10"
36	5'-0"	11'-6"	20'	4'-1"
38	5'-4"	12'-2"	22'	4'-6"
40	5'-7"	12'-3"	24'	4-11"
42	5'-9"	13'-4"	25'	5-1"

4 - 4 POINT PICKUP



4-4 POINT PICKUP TRIAL LOCATIONS					
H	A	B	L	C	D
18'	3'-3"	7'-7"	18'	4'-8"	2'-0"
20'	3'-7"	8'-4"	20'	5'-3	2'-1½"
22	3-11"	9'-3"	22'	5'-10	2'-3"
23	4'-2"	9-7"	24'	6'-4"	2'-6"
24	4'-4"	10'-1"	26'	6'-10"	2'-9"
25	4'-6"	10'-6"	28'	7'-4"	3'-0"
26	4'-8"	11'-0"	30'	8'-0"	3'-0"
27	4'-10"	11'-4"	32'	8'-6"	3'-4"
28	5'-0"	11'-9"	34'	9'-0"	3'-6"
29	5'-2"	12'-2"	36'	9'-6"	3'-8"
30	5'-4"	12'-7"	38'	10'-2"	3'-10"
31	5'-7"	13'-0"	39'	10'-4"	4'-0"
32	5'-9"	13'-4"	40'	10'-6"	4'-3"

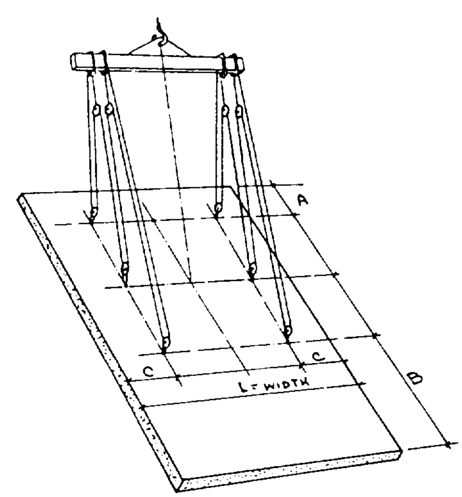


Figure 6-11.-Different types of pickup points.

RECOMMENDED READING LIST

NOTE

Although the following references were current when this TRAMAN was published, their continued currency cannot be assured. You therefore need to ensure that you are studying the latest revision.

Concrete and Masonry, FM 5-742, Headquarters, Department of the Army, Washington, D.C., 1985.

Concrete Formwork, Keel, Leonard, American Technical Publishers, Inc., Homewood, 111., 1988.

Design and Control of Concrete Mixtures, Portland Cement Association, Skokie, Ill., 1988.